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# (54) Actuator position control with inductive sensing

(57) An actuator position control system for brush-type DC motors. The system includes a sensing inductor, amplifier, central control unit (microprocessor), and motor driver. The system utilizes the differential signal di/dt to indicate the falling edges of commutation spikes in the motor current profile. An inductor is selected as the signal sensor, because voltage drops across the inductor are directly proportional to di/dt. The voltage drop, L(di/dt), across the inductive sensor is input to the amplifier, amplified, and then sent to the microprocessor. The microprocessor reads the output pulses from the amplifier and compares the pulse count to an input command signal. The microprocessor then sends shaft position control information to the motor driver.

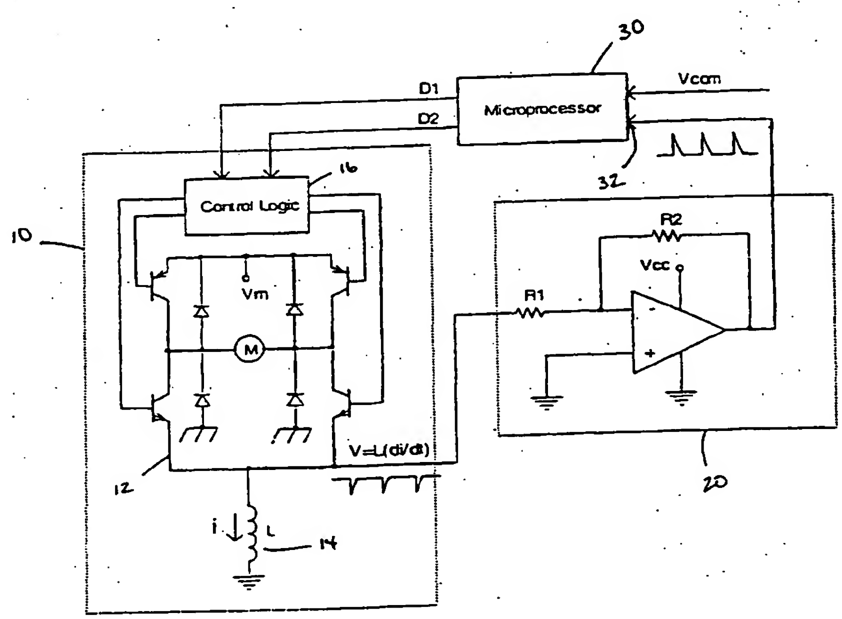


Figure 1



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**Description**

## BACKGROUND OF THE INVENTION

### Field of the Invention

**[0001]** The present invention relates to position control systems of actuators with brush-type permanent magnet DC motors and, more particularly, to actuator position control systems utilizing commutation pulse feedback.

### Description of the Related Art

**[0002]** The feedback signals of actuator position control systems are normally achieved by using encoders, resolvers, or potentiometers. More recently, commutation pulses embedded in the current of brush-type permanent magnet DC motors have been used as feedback signals (referred to as "pulse count").

**[0003]** Encoders and resolvers can provide good accuracy and reliability but they are too expensive for applications like HVAC control in automobiles. Potentiometers have been a popular choice for such low cost applications.

**[0004]** The typical arrangement for a potentiometer actuator includes a brush-type permanent magnet DC motor, and a gear train to increase the output torque. The potentiometer is driven either directly by the output shaft (wiper and carbon traces), or through another gear driven by the output gear. The output voltage as measured from the center tap of the potentiometer is then used to determine the output shaft position.

**[0005]** Due to the mechanical contact (wiper and carbon traces), the accuracy, stability and reliability of such potentiometer systems is significantly compromised. In addition, the cost of such systems is still relatively high.

**[0006]** Pulse counting is done through monitoring of DC motor current signals. A sensor is connected to the motor power line to sense the current ripples due to commutation and, with a fixed design, the number of the ripples per shaft revolution is a constant. As a result, the motor shaft position can be determined accurately according to the pulse counting result.

**[0007]** Resistors can be used as sensors for current signal detection via different kinds of connections to the motor power lines. However, due to the high variation in current profile, as well as the environment and life of the systems, the accuracy and reliability of such sensor systems may be adversely affected. Furthermore, the sensing resistor also results in poor system efficiency, which means a bigger actuator is needed for the same application because the resistance must be large enough for sufficient signal sensing.

**[0008]** Therefore, accuracy and reliability have become obstacles to development of actuator position control systems, especially for control systems in automotive applications. Accordingly, a low cost solution with a simple circuit and high system efficiency is desirable.

## SUMMARY OF THE INVENTION

**[0009]** In view of the foregoing, one object of the present invention is to overcome the difficulties of complexity and cost found in prior art actuator position control systems.

**[0010]** Another object of the invention is a pulse count system for brush-type DC motors that uses inductive sensing for clean, accurate, and reliable shaft position signals to provide accurate actuator position control.

**[0011]** A further object of the invention is an inductive sensing actuator position control system that exhibits high system efficiency, smooth actuator operation, and insensitivity to motor life and environmental temperature change.

**[0012]** A still further object of the invention is a simple circuit design for actuator position control that provides a highly --reliable system at low cost.

**[0013]** In accordance with these and other objects, the present invention is directed to an actuator position control system for brush-type DC motors. The system includes a signal sensor, an amplifier, a central control unit such as a microprocessor, a motor driver and a permanent magnet DC motor. An inductor is selected as the signal sensor, because voltage drops across the inductor are directly proportional to di/dt. The voltage drop, L(di/dt), across the inductive sensor is input to the amplifier. The output pulses from the amplifier are sent to the microprocessor to determine output shaft position, and speed control can also be achieved using the output pulse information.

**[0014]** These together with other objects and advantages which will become subsequently apparent reside in the details of construction and operation as more fully hereinafter described and claimed, reference being had to the accompanying drawings forming a part hereof, wherein like numerals refer to like parts throughout.

## BRIEF DESCRIPTION OF THE DRAWINGS

**[0015]**

Figure 1 is a schematic drawing of the system circuit in accordance with the present invention;

Figure 2 is a flow chart depicting the working process of the present invention;

Figure 3 is a schematic drawing of the driving circuit showing the current flow in accordance with the present invention;

Figure 4 is a graph illustrating the current waveform of the permanent magnet DC motor; and

Figure 5 is a block diagram of a second embodiment of the pulse count system of the present invention with a pulse regulator.

## DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0016] In describing a preferred embodiment of the invention illustrated in the drawings, specific terminology will be resorted to for the sake of clarity. However, the invention is not intended to be limited to the specific terms so selected, and it is to be understood that each specific term includes all technical equivalents which operate in a similar manner to accomplish a similar purpose.

[0017] The system of the present invention, as illustrated in the circuit diagram of Figure 1, is based on inductive sensing. More particularly, the system operates by monitoring changes in current signals from the motor through voltage across the inductor. Voltage drops across the inductor are directly proportional to the time rate of change of the current, di/dt. The system utilizes the differential signal di/dt to amplify the falling edges of commutation spikes in the motor current profile and sense output shaft position.

[0018] As shown in Figure 1, the system includes a motor and driver 10, an amplifier 20 and a microprocessor 30. The motor and driver 10 includes a driving circuit 12, a sensing inductor 14, and control logic 16. The sensing inductor 14 is connected in series with and senses a signal from the motor M. The sensed signal is fed to the amplifier 20. The polarity of the signal is reversed, and the magnitude of the signal is amplified, such as to 5 volts, in order for the microprocessor 30 to better read the output pulses from the amplifier 20.

[0019] Typically, there are a number of high frequency noises in the pulses due to brush bounce and other causes. The control software in the microprocessor is configured to enable the microprocessor to eliminate false readings. More particularly, the microprocessor includes a pulse reading input/output (I/O) port 32 which receives the incoming pulses from the amplifier 20. The pulse reading I/O port 32 is programmed so as to be sensitive to only the rising edges of the pulses. An interrupt service routine is triggered by the rising edge of each pulse and the pulse is counted. The I/O port 32 is then masked for most of the remainder of the pulse period to filter out noise. For a good filtering result, the masking time of the I/O port needs to be determined dynamically. In addition, the sensing inductor by nature also helps to filter electrical noises, enhancing the reliability of the system without the need for expensive filters.

[0020] A command input to the microprocessor, Vcom, which is generally an analog input, triggers the control process which is summarized in Figure 2. Upon start of the system, a calibration process 42 is initiated to determine the full range of travel of the motor (or actuator) and the current position of an associated structure being controlled, such as a door on a plenum of an HVAC system. During calibration, the number of pulses necessary to complete the full range of travel between positional limits is determined. The number of motor shaft revolutions is directly related to the number of pulses. For example, a DC motor having three coils and two poles, which represents the preferred embodiment, should have six pulses per revolution. Thus, the number of revolutions of the motor shaft necessary to complete the full range of motion from one positional limit to the other is 50, assuming the number of pulses for the full range of travel is 300. Following calibration, the system is ready to accept commands.

[0021] Upon receipt of the analog input, Vcom, triggering the control process, the microprocessor reads 44 and converts the analog command to a digital signal. The converted input is then associated with the position of the motor shaft in pulses. For example, assuming the input is 50% of the maximum input which represents the overall travel of the actuator, and the number of pulses for the full travel is 300, then the number of pulses representing the current input command is 150. The pulse count result is then read 46 and compared 48 with the digital command signal to determine the mode of the actuator. If there is a difference 50 between the pulse count and the digital command signal, driving of the actuator 52 is initiated. In the absence of a difference 50, the control process ends 54. The conversion and comparison may be accomplished in software or may be implemented using a separate analog-to-digital converter and comparator, or similar structures, as would be known by persons of skill in the art.

[0022] The actuator working modes include FORWARD, REVERSE, BRAKING and STOP. In FORWARD mode the actuator is driven in a clockwise direction; in REVERSE mode, the actuator is driven in a counter-clockwise direction. The processor 30, in response to a difference between the pulse count and the digital command signal, issues an appropriate command to the motor and driver 10 through data lines D1 and D2, in response to which the actuator (or motor M) is driven until the desired position is achieved. For example, if the digital command signal indicates a desired position at 30 revolutions and the pulse count indicates the current motor position is at 25 revolutions, the driving circuit 12 applies voltage to the motor M, drives the motor (actuator) in the appropriate direction to reduce the position difference to zero (five revolutions), and then cuts off the voltage to the motor and awaits a next command.

[0023] The control logic 16 controls which transistors are on or off, in response to the commands from the microprocessor. While software may be used, the control logic 16 is preferably embodied in hardware. The control logic may be set up to respond to the command signals received from D1 and D2 in a number of ways. For example, if D1 is logical "1" and D2 is logical "0", then FORWARD operation is indicated and source driver T1 and sink driver T2 are turned on. Conversely, if D1 is "0" while D2 is a logical "1", then REVERSE mode is indicated and source driver T3 and sink driver T4 are turned on. If both D1 and D2 are "0", then BRAKING is indicated

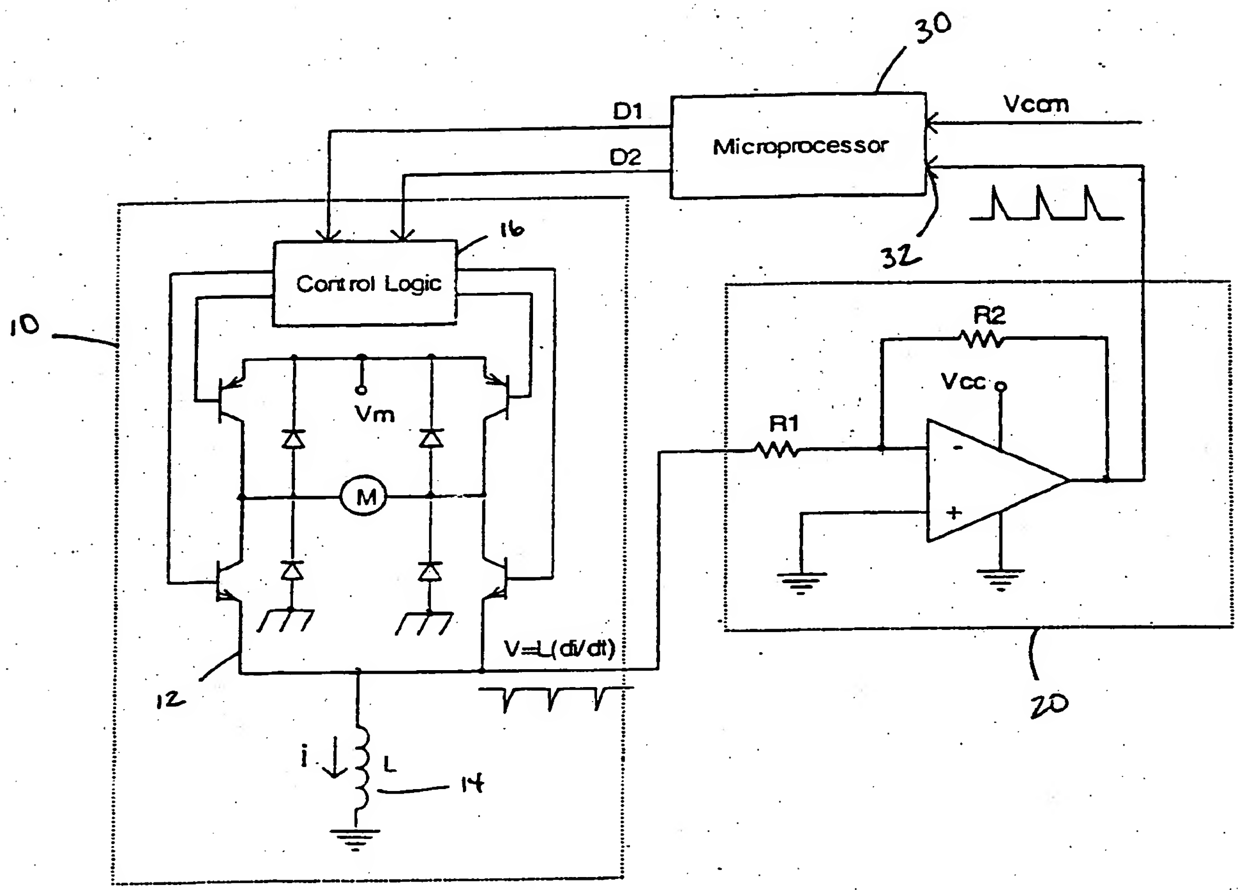
30
D1
D2
Microprocessor
Vcm
32
16
Control Logic
10
Vm
M
R2
Vcc
R1
-
+
V=L(di/dt)
12
20
i
L
14

Figure 1

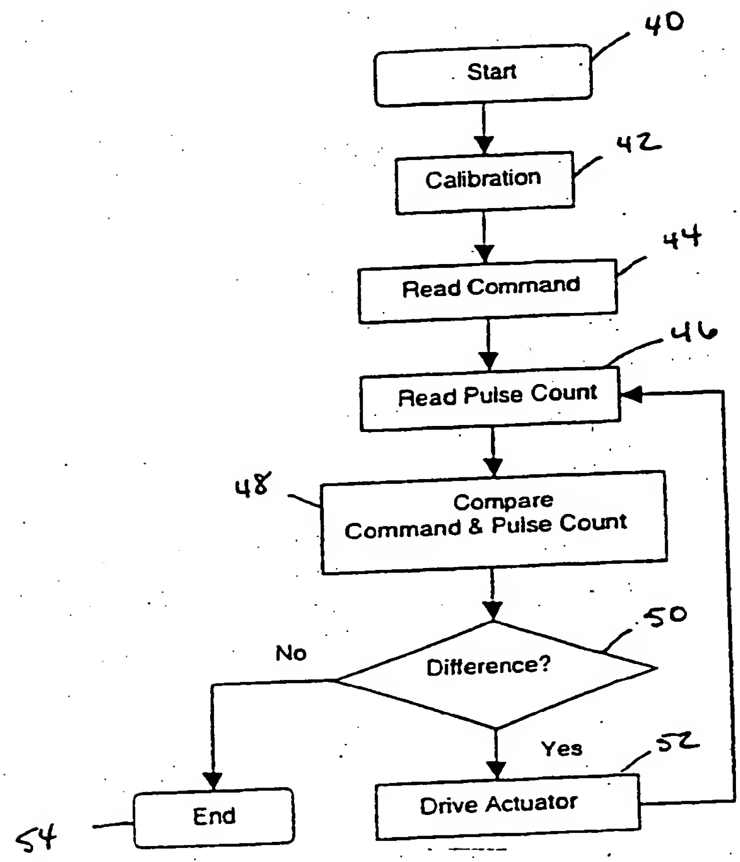
40
Start
42
Calibration
44
Read Command
46
Read Pulse Count
48
Compare
Command & Pulse Count
50
Difference?
No
Yes
52
End
Drive Actuator
54

Figure 2

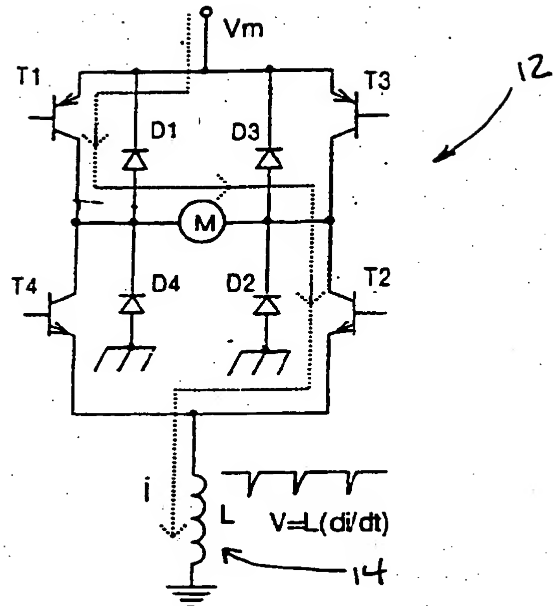


Figure 3

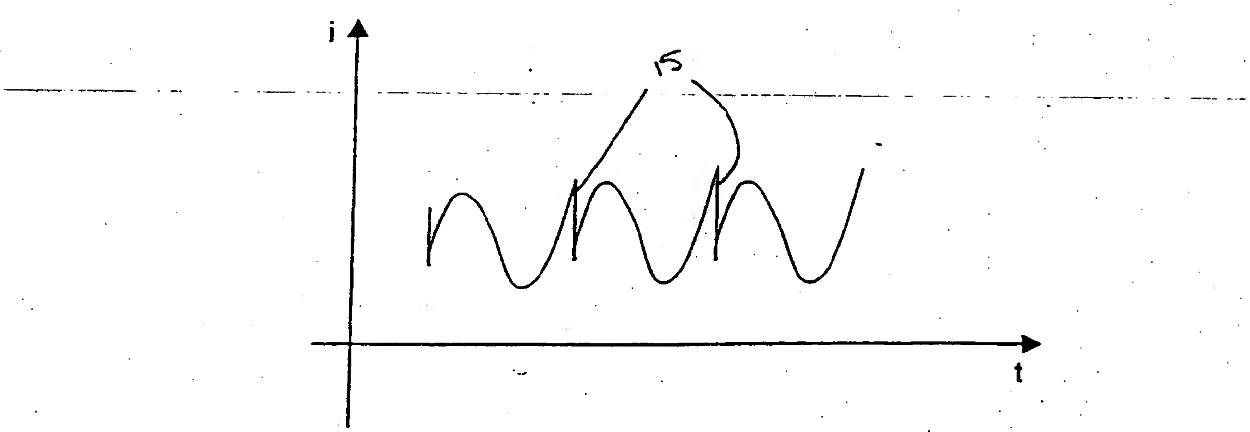


Figure 4

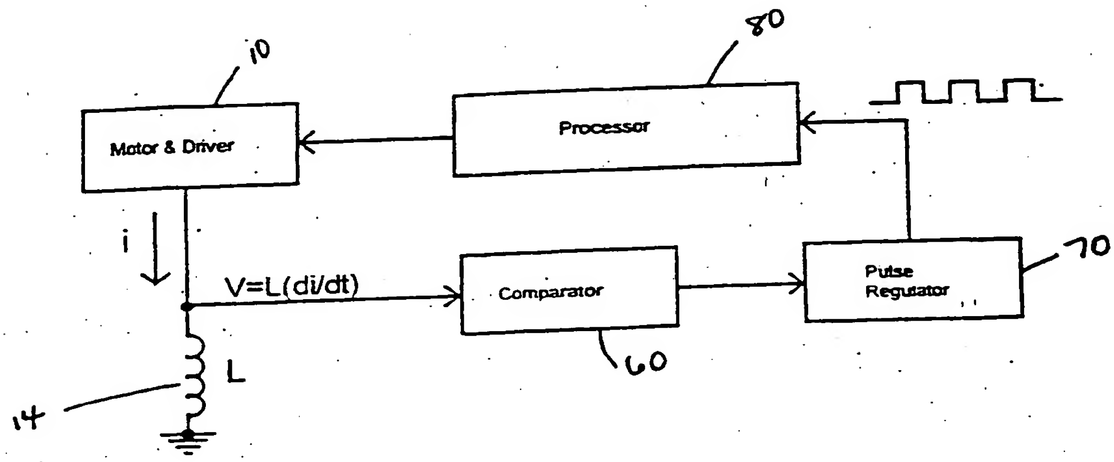
80
10
Processor
Motor & Driver
i
V=L(di/dt)
Comparator
Pulse
Regulator
70
60
L
14

FIG. 5